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Yuanqiang Cai
Zhejiang University, Hangzhou, China

Shiming Wu
Zhejiang University, Hangzhou, China

Yunmin Chen
Zhejiang University, Hangzhou, China

Changjie Xu
Zhejiang University, Hangzhou, China

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Behavior of Double-row Pile Retaining Structure for Deep Excavation in Soft Clay

Cai yuanqiang, Wu shiming, Chen yunmin and Xu changjie
Deptaremnet of Civil Engineering, Zhejiang University, China, 310027

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ABSTRACT

An excavation of 10.5m deep and 110m × 70m in plane with double-row pile retaining structure in soft clay has been completed, which is of several advantages, such as elimination of lateral deflection and ground surface settlement, low cost and short duration of excavation. This paper presents the design considerations, procedure of construction and excavation, behavior of this type of retaining structure. The FEM analysis has been carried for prediction of lateral deflection and stress, the results from FEM method conformed well with field measurement, some conclusions drawn from the design and construction will be valuable for future construction in similar engineering.

KEYWORDS

double-row piles, retaining structure, excavation, FEM analysis, deflection monitoring

INTRODUCTION

With the development of Chinese economy, many high buildings with multi-level basement are built in many the southeast coastal cities with deep deposits. Design and construction of deep pit excavation become a common issue for geotechnical engineers. The cost, safety and time limit of the project are three main essential factors for design.

Double-row piles retaining structure is one of effective structures, see Fig.1. It consists of double-row piles, which are usually connected by beam. For large and deep pit, this type of structure is of advantages: great lateral stiffness to eliminate deflection effectively, without installation brace resulting in short time limit of construction, and so on (Li yongsheng, 1996) . The aim of this paper is to discuss some factors that affect the deflection and stress by FEM analysis and field measurement.

BRIEF OF THE PROJECT

Deep excavation of project of Zhijiang Mansion in Shanghai east side of Huangpu River is one successful example of application of the technique. The pit was almost no margin close to two main roads on its south and north sides and in between of Yinqiao Mansion and Xinlu Mansion (which was unconstructed at that time) on the other direction. Zhijiang

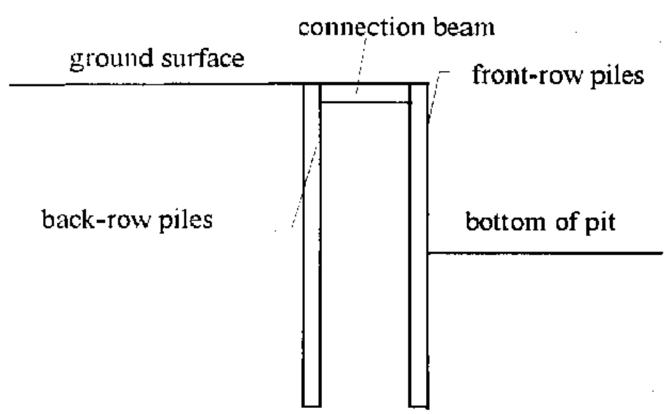

Fig. 1 Double-row pile retaining structure system

Mansion, fan-shaped building consists of one 18-story and one 28-story building with 2-level basement. The pit was by 70m, with depth of 10.5m and 12.5m in some area. Soil profile of this project is shown in Table 1 and the shape of pit is shown in Fig.2.

Table 1. Soil profile

Layers	D	e	w	ρ	C	ϕ
Fill	3.0			18.5	0	30
silty clay	2.0	0.884	31.86	19.2	20.1	16.8
mucky clay	7.8	1.284	45.33	17.5	13.2	11.3
clay	9.5	1.40	49.59	17.1	11.3	9.6
clayey silt	5.0	1.02	36.0	18.4	26.9	13.5
sandy clay	4.0	0.679	24.0	20.2	50.0	20.5

D: Average Thickness(m) e: Void Ratio w: Water Content ρ: Unit Weight(KN/m^3) C: Cohesion(KPa) ϕ :Friction Angle

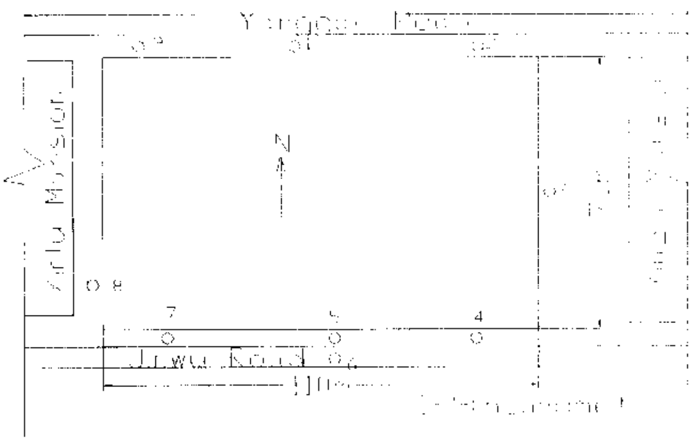

Fig.2 Pit shape and location of geotechnical instruments

DESIGN AND CONSTRUCTION

The profile showed the excavation was in soft clay layers. Considering a large volume of soils to be excavated, excavation can`t be completed in scheduled period of time if braced excavation is adopted for its' inconvenience. On the other hand, a great deflection would occur, which would lead to high cost if other type of retaining structure is adopted other than double-row piles retaining structure. According to the analysis above, designers decided to employ double-row piles retaining structure for excavation. The system consisted of double-row ϕ 800 RC-casted in place piles, with length of 20m. spacing of front-row piles is 1.0m and 2.0m for back-row piles. Two rows of piles is connected by connection beam with height of 1.0m form Π-shaped frame structure. Distance between two rows of piles is 4.0m. To reduce the deflection of structure and increase passive earth pressure, grid-shaped soil-cement mixed columns are adopted to strengthen the bottom part of pit. Cross section of the pit and detailed plane of piles are shown in Fig.3 and Fig.4 respectively. Calculation indicated that stability coefficient was about 1.72 and anti-slide coefficient was about 1.64. Other calculated results also met demands of design.

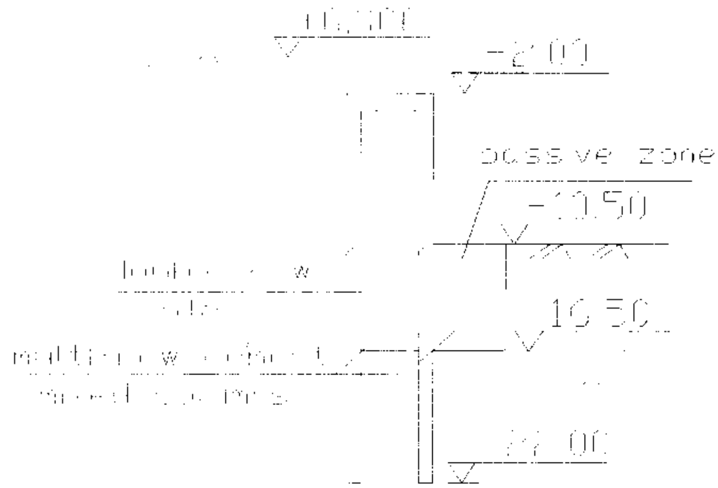

Fig.3 Cross-section of pit

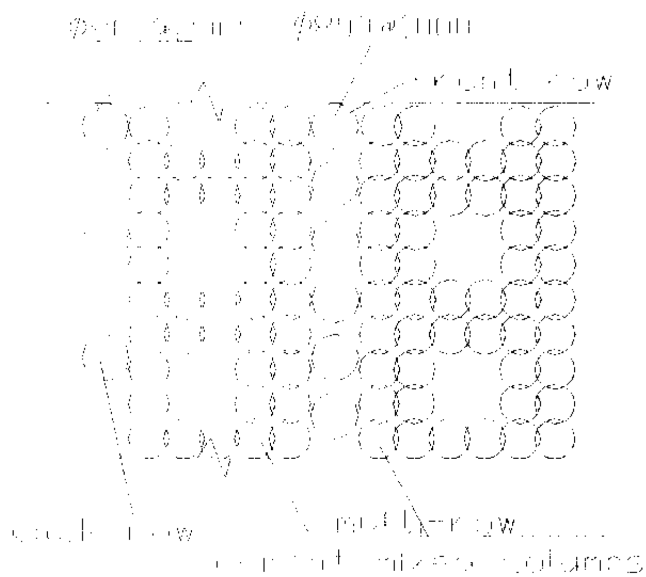

Fig.4 Detailed plane view of mixed columns

The excavation was divided into two stages and three sections from east to west, first to depth of 6.0m and the second depending on the order of section of concrete construction. Since there was no brace installed, it was convenient to excavate and the whole course lasted about two months, even though encountering bad weather.

FEM ANALYSIS FOR MECHANICAL BEHAVIOR OF THE DOUBLE-ROW PILES RETAINING STRUCTURE

FEM analysis was carried out to study mechanics behavior of the structure. Soil element with 8-node isoparameter element, elastic beam element for piles and connection beam are adopted. Passive zone strengthened by cement mixed columns is taken as elastic element. Stress-strain relation Duncan-Zhang non-linear model is adopted in which parameters are easy to determine(Chang and Duncan, 1970). Tangent modulus is determined by following equation:

$$E_t = E_i(1 - R_f D_s)^2 \qquad (1)$$

where, E_i:initial tangent modulus,

R_f:destroy ratio,

D_s:stress level.

Unloading modulus is given as:

$$E_{tu} = K_u \cdot Pa \cdot \left(\frac{\sigma_3}{Pa}\right)^n \qquad (2)$$

where: Pa is air pressure and σ_3 is minimum principal stress.

According to experimental data and engineering experience in Shanghai, parameters of Duncan-Zhang model for this project are given in Table 2.

Table 2. Parameters of Duncan-Zhang model

Layers	K	K_u	n	R_f
silty clay	87	165	0.64	0.83
mucky clay	68	146	0.72	0.68
clay	66.3	125.6	0.75	0.65
clayey silt	85.6	150	0.65	0.80
sandy clay	91	188	0.63	0.85

Stress, moment and deflection of structure were studied. Fig.5 shows the deflection curves of front-row piles and back-row piles. It can be seen that the maximum deflection occurs at the top of piles. Deflection of 1/4 length of front-row piles is very close to maximum deflection and decreases gradually with the increasing of the depth below that depth. Deflection of back-row piles is less than that of front-row piles and decreases downward from the top of piles. All indicates that interaction between two rows of piles exists.

Figure 6 presents moments of two rows of piles. Seen from two Figs., we can find that two rows of piles are subjected to alternating stress, and have a moment inflection-point, i.e., the sign of moment at the top of piles is opposite to that of moment at the bottom of piles. Maximum moment of front-

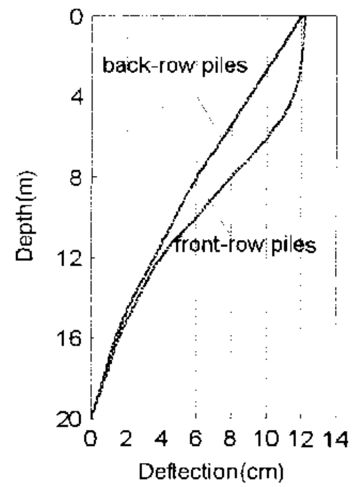

Fig.5 Deflections of two rows of piles.

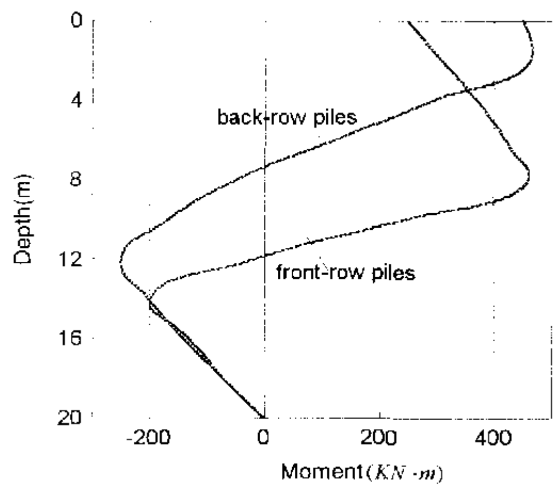

Fig.6 Moments of two rows of piles

row piles occurs nearby the bottom of pit while that of back-row piles occurs nearby the top of pile.

Some comparative conditions were studied by FEM and some behaviors of double-row piles retaining structure were found. For example, under the condition of total stiffness equate, double-row piles system can be more effectively to eliminate deflection of pit than single-row pile; only as the distance between two rows of piles is about 4d (d is the diameter of piles), the structure of two rows of piles could interact to control deflection effectively; if passive zone is strengthened, passive earth pressure will be increased and the deflection of structure will be reduced effectively.

MONITORING AND FEM ANALYSIS

Monitorings of settlement on ground surface, deflection over the front-row of piles and the top beam of the structure were undertaken for the safety in the whole procedure of excavation.

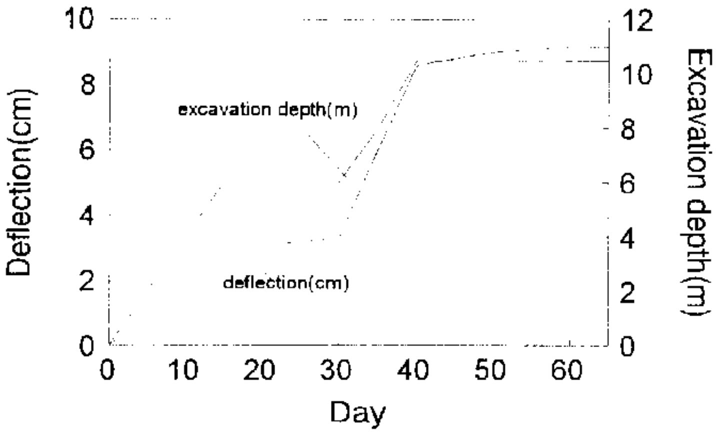

Fig.7 Measured deflection of top beam during excavation.

Location of inclinometers is shown in Fig.2. Fig.7 shows the measured deflection of the top beam. Fig.8 shows the measured deflection of the front-row of piles, measured by No.3 inclinometer. FEM prediction is also presented in the figure.

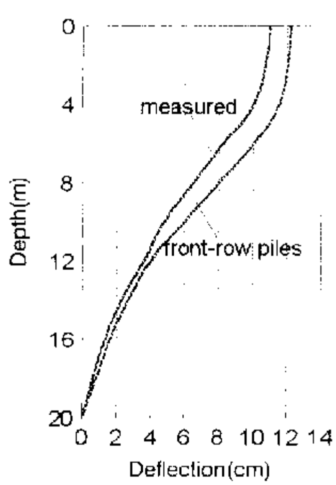

Fig.8 No.3 inclinometer measured and FEM predicted deflection of front-row piles.

It can be seen from Fig.7 that the deflection of retaining structure increases with increasing of depth of excavation and accelerates as excavation approaching the bottom of the pit. Since reasonable design, the deflection is rather small even though large scale of pit. Fig.8 shows that the measured results agree well with that analyzed by FEM. i.e., FEM method of this paper is effective for studying the behavior of double-row piles retaining structure.

CONCLUSIONS

From the project as a whole, the following conclusions can be drawn:

1. The double-row pile retaining structure is an effective method to deal with deep excavation in soft clay. It can eliminate deflection more effectively than single-row pile retaining structure. In addition, it is convenient to construct since no brace installed when adopt this technique.
2. It is very important to determine suitable distance between two rows of piles. only as the distance is about 4d, the retaining structure of two rows of piles can interact effectively.
3. If passive earth pressure section is strengthened, the retaining structure can function more effectively to control deflection of structure. For deep and large pit, multi-stage procedure excavation is recommended.
4. Excavation is a complicated geotechnical problem and there are many unpredictable factors that maybe take effect. In order to assure the safety of the pit, monitoring of deflection, settlement of ground surface and sometime pore-water pressure are necessary.

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